MODIS Science Team Meeting 2012

Remote sensing of ice crystal asymmetry parameter

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Thanks to Tim Garrett, Ping Yang, Bryan Baum, Igor Geogdzhayev, MAS team

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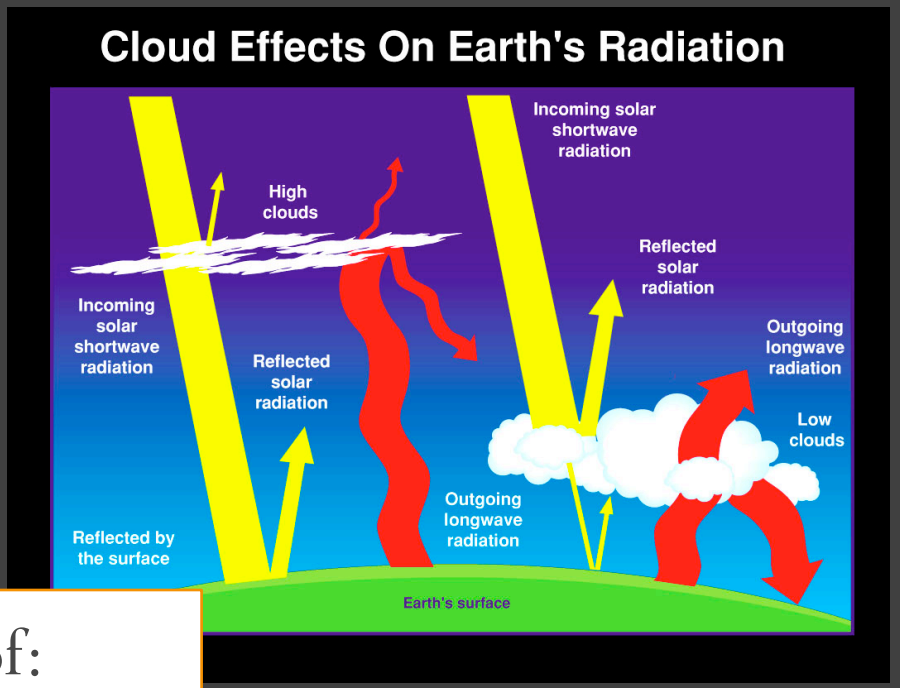
Ice clouds in climate models

- Climate models need improve representation of ice cloud
  - Macrophysical properties
  - Microphysical properties
  - Optical properties



Cloud reflection is function of:

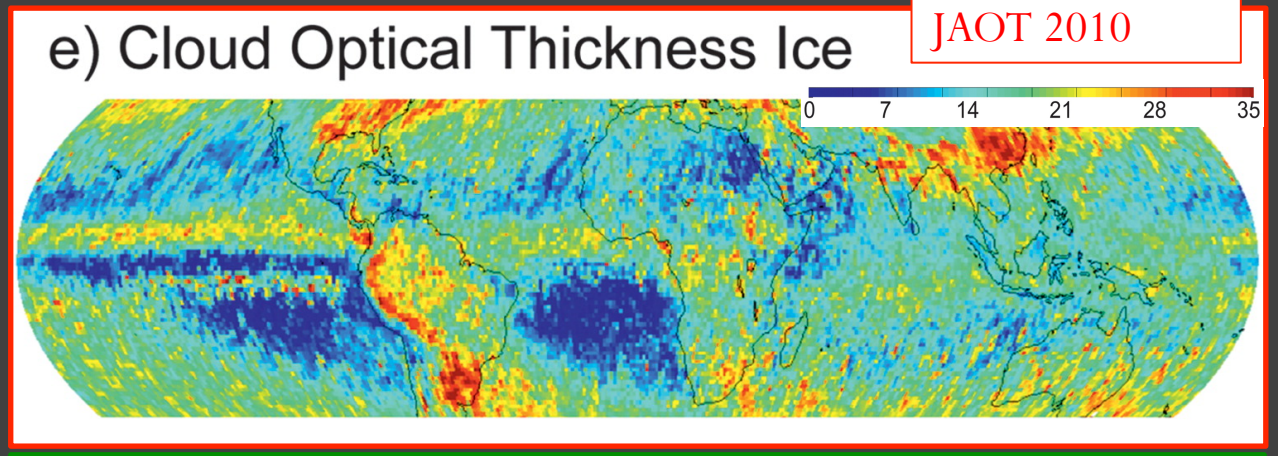
- Optical thickness τ
- Single scattering albedo ω_0 (R_{eff})
- Asymmetry parameter g

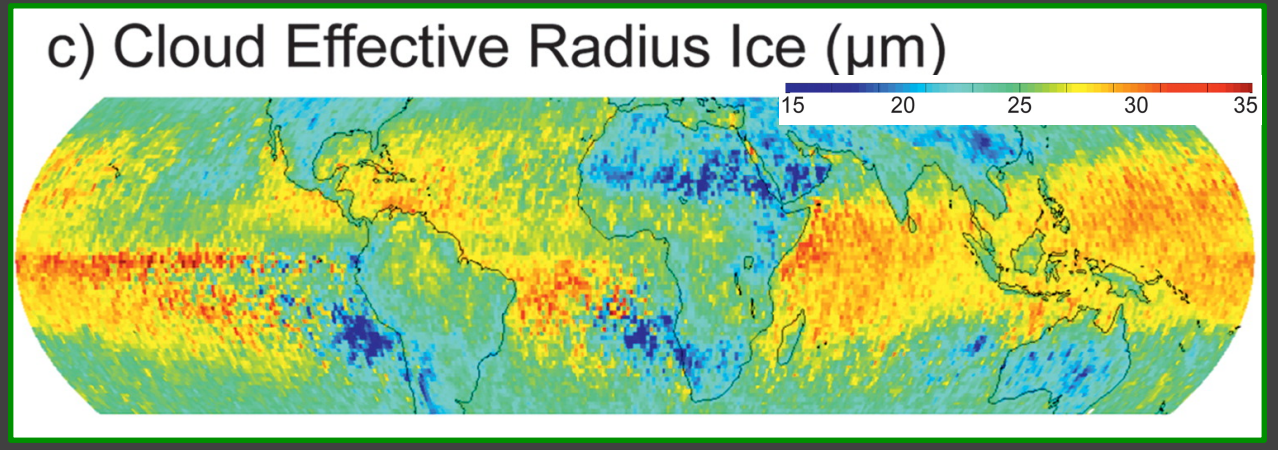
Global ice cloud properties

- Visible + SW-infrared reflectances:
  - Optical thickness
  - R_{eff}
- Nakajima-King method

- Global asymmetry parameter unconstrained

Maddux et al., JAOT 2010





Ice cloud asymmetry parameter:

Models: 0.6-0.95

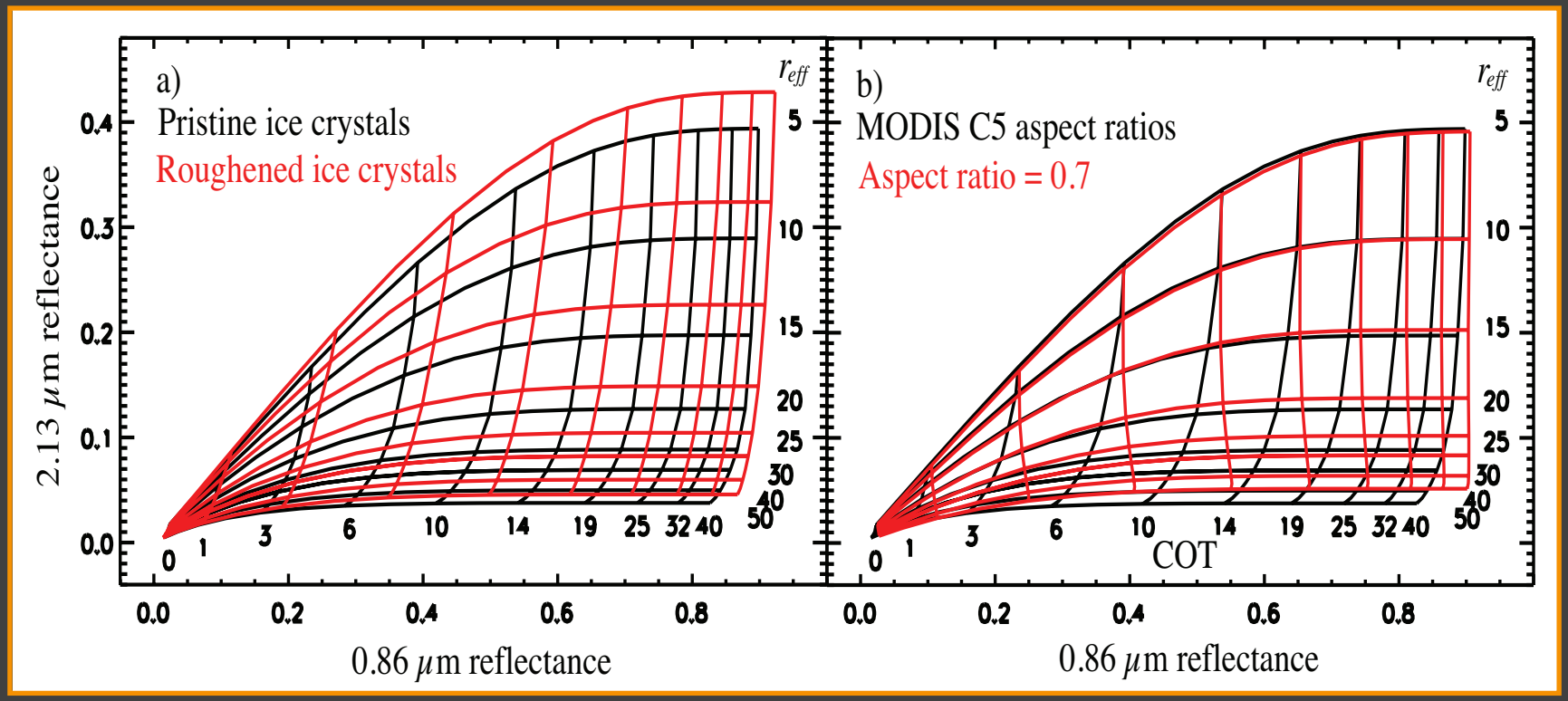
In situ: ~0.75

Required accuracy: 0.01-0.04 (Vogelmann & Ackerman, 1995)

?

?

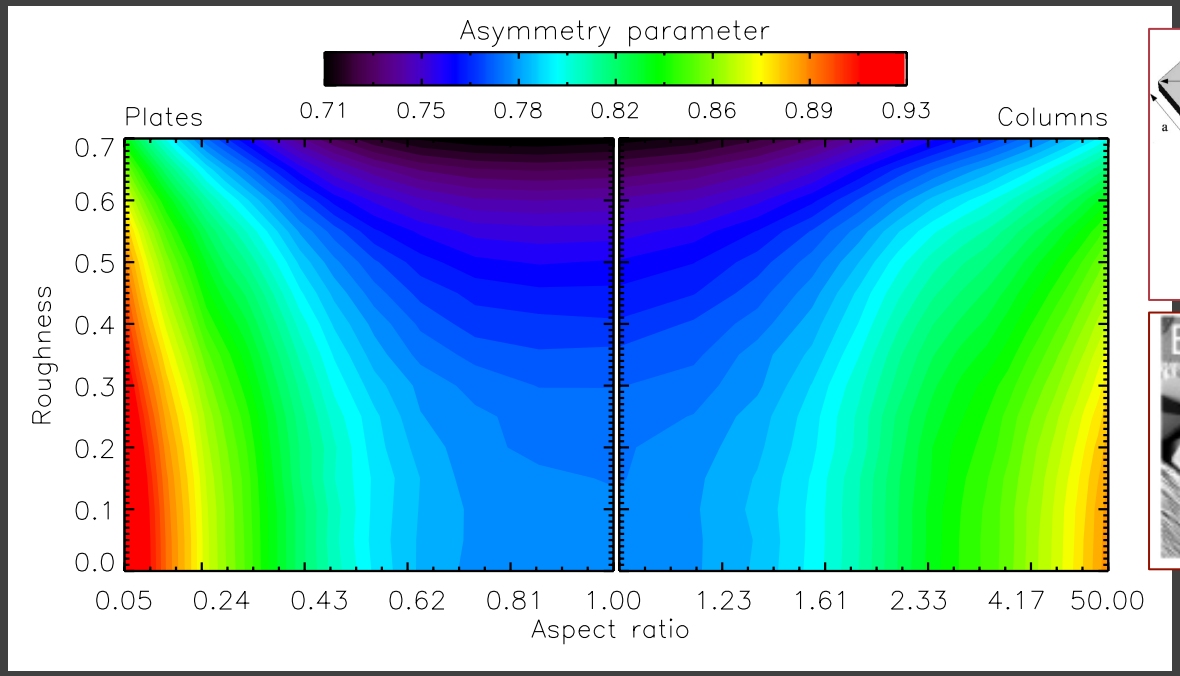
Nakjima-King method depends on asymmetry parameter

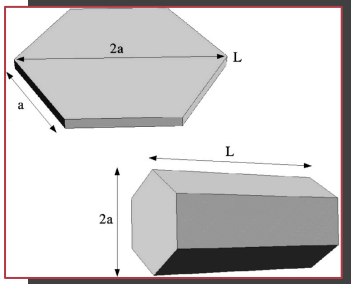


- Assuming lower g leads to
  - Larger R_{eff}
  - Lower optical thickness

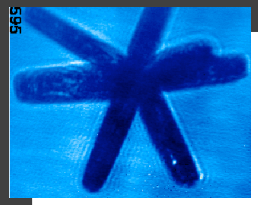
Ice crystal asymmetry parameter

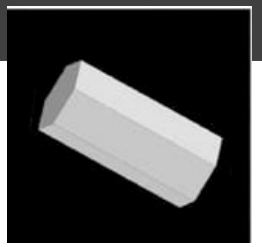
- Ice crystal g mainly depends on
  - Shape (mostly aspect ratio)
  - Microscopical Roughness/impurity





Complex vs simple ice crystals

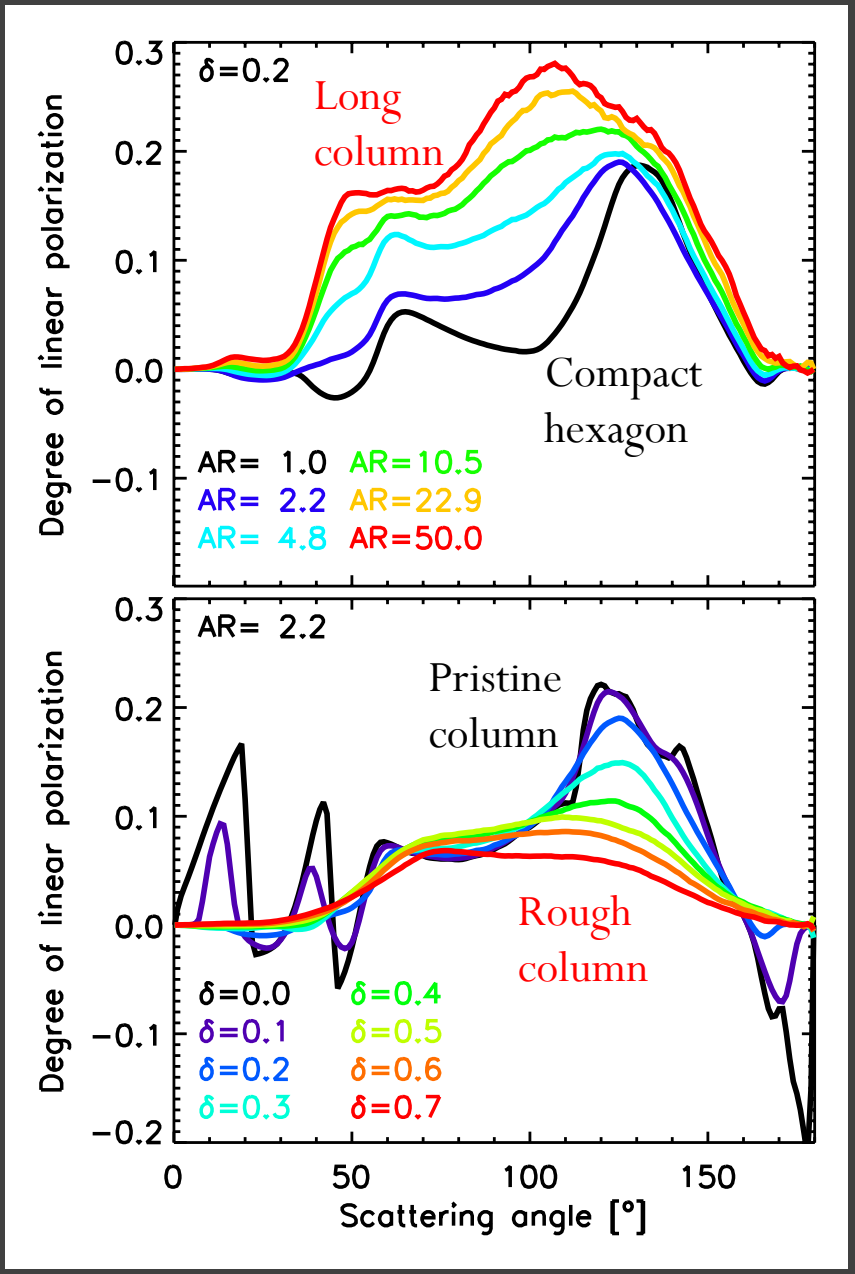




- Phase matrix $\mathbf{P}_{complex} \approx \mathbf{P}_{components}$ (Fu 2007; Um & McFarquhar 2007; 2009)

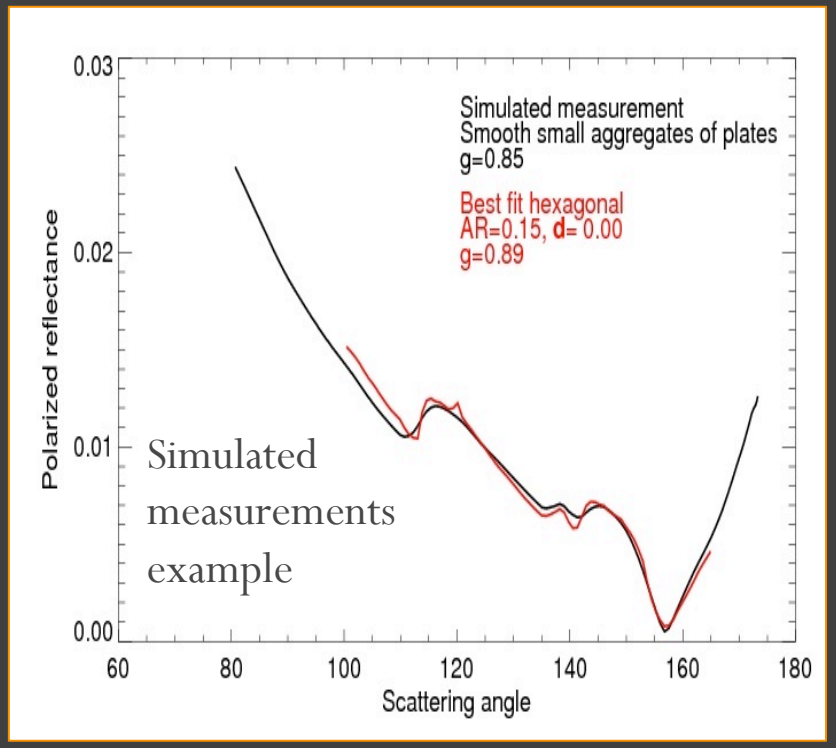
Polarization dependence on aspect ratio & roughness

- Polarization contains info about aspect ratio and roughness
- Single scattering features largely conserved in multi-directional polarized reflectance measurements (as measured by e.g, POLDER)



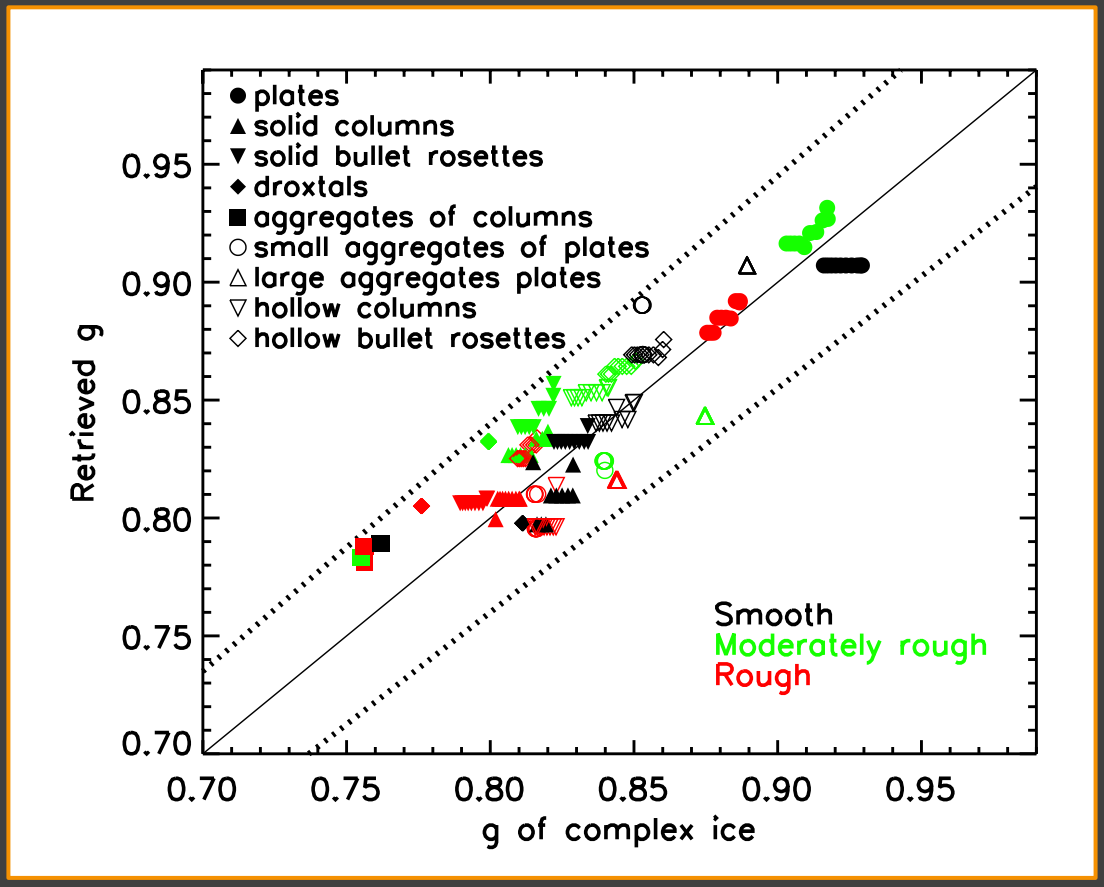
Retrieval procedure

- Use columns/plates as proxies for complex crystals
- LUT of polarized reflectances for columns/plates
  - 51 aspect ratios 0.02 – 50
  - 15 roughness values (δ =0 – 0.7)
- Find best fit to measured polarized reflectances
  - 100 – 165 scattering angle in examples
- Asymmetry parameter of best-fit hexagon is retrieved g

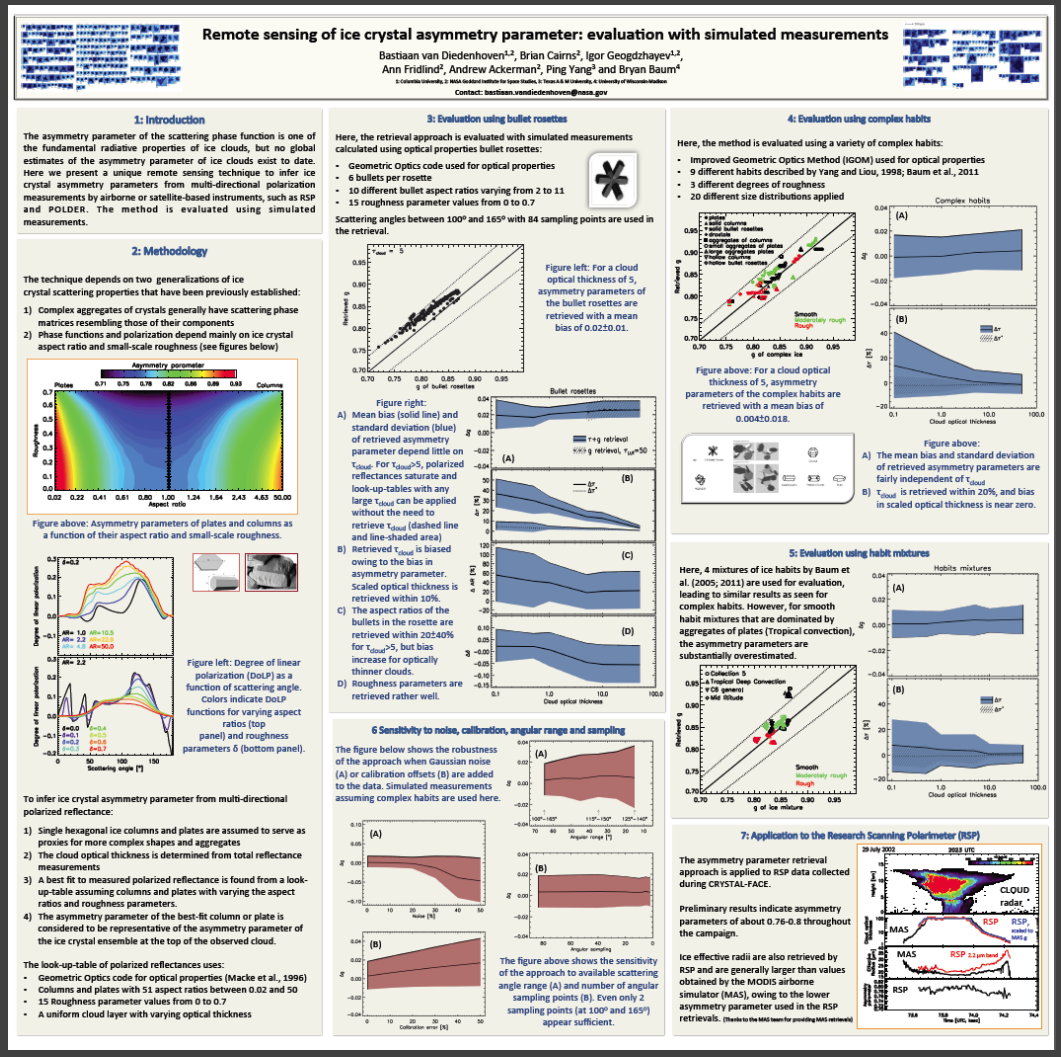


Simulated data test

- Simulated data:
  - Complex ice optical properties (Yang et al.)
  - 20 different size distributions
  - 3 roughness degrees
- Retrieved g_0
  - Within 5%
  - Mean bias: 0.004
  - Standard deviation: 0.02



More evaluation of method with simulated measurements on poster



Remote sensing of ice crystal asymmetry parameter: evaluation with simulated measurements

Bastiaan van Diedenhoven[1,2], Brian Cairns[2], Igor Geogdzhayev[1,2], Ann Fridlind[2], Andrew Ackerman[2], Ping Yang[3] and Bryan Baum[4]

1: Columbia University, 2: NASA Goddard Institute for Space Studies, 3: Texas A & M University, 4: University of Wisconsin-Madison

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1: Introduction

The asymmetry parameter of the scattering phase function is one of the fundamental radiative properties of ice clouds, but no global estimates of the asymmetry parameter of ice clouds exist to date. Here we present a unique remote sensing technique to infer ice crystal asymmetry parameters from multi-directional polarization measurements by airborne or satellite-based instruments, such as RSP and POLDER. The method is evaluated using simulated measurements.

2: Methodology

The technique depends on two generalizations of ice crystal scattering properties that have been previously established:

1) Complex aggregates of crystals generally have scattering phase matrices resembling those of their components
2) Phase functions and polarization depend mainly on ice crystal aspect ratio and small-scale roughness (see figures below)

Figure above: Asymmetry parameters of plates and columns as a function of their aspect ratio and small-scale roughness.

Figure left: Degree of linear polarization (DoLP) as a function of scattering angle. Colors indicate DoLP functions for varying aspect ratios (top panel) and roughness parameters δ (bottom panel).

To infer ice crystal asymmetry parameter from multi-directional polarized reflectance:

1) Single hexagonal ice columns and plates are assumed to serve as proxies for more complex shapes and aggregates
2) The cloud optical thickness is determined from total reflectance measurements
3) A best fit to measured polarized reflectance is found from a look-up-table assuming columns and plates with varying the aspect ratios and roughness parameters.
4) The asymmetry parameter of the best-fit column or plate is considered to be representative of the asymmetry parameter of the ice crystal ensemble at the top of the observed cloud.

The look-up-table of polarized reflectances uses:

- Geometric Optics code for optical properties (Macke et al., 1996)
- Columns and plates with 51 aspect ratios between 0.02 and 50
- 15 Roughness parameter values from 0 to 0.7
- A uniform cloud layer with varying optical thickness

3: Evaluation using bullet rosettes

Here, the retrieval approach is evaluated with simulated measurements calculated using optical properties bullet rosettes:

- Geometric Optics code used for optical properties
- 6 bullets per rosette
- 10 different bullet aspect ratios varying from 2 to 11
- 15 roughness parameter values from 0 to 0.7

Scattering angles between 100° and 165° with 84 sampling points are used in the retrieval.

Figure left: For a cloud optical thickness of 5, asymmetry parameters of the bullet rosettes are retrieved with a mean bias of 0.02±0.01.

Figure right:

A) Mean bias (solid line) and standard deviation (blue) of retrieved asymmetry parameter depend little on τ_{cloud}. For $\tau_{cloud}>5$, polarized reflectances saturate and look-up-tables with any large τ_{cloud} can be applied without the need to retrieve τ_{cloud} (dashed line and line-shaded area)
B) Retrieved τ_{cloud} is biased owing to the bias in asymmetry parameter. Scaled optical thickness is retrieved within 10%.
C) The aspect ratios of the bullets in the rosette are retrieved within 20±40% for $\tau_{cloud}>5$, but bias increase for optically thinner clouds.
D) Roughness parameters are retrieved rather well.

6 Sensitivity to noise, calibration, angular range and sampling

The figure below shows the robustness of the approach when Gaussian noise (A) or calibration offsets (B) are added to the data. Simulated measurements assuming complex habits are used here.

The figure above shows the sensitivity of the approach to available scattering angle range (A) and number of angular sampling points (B). Even only 2 sampling points (at 100° and 165°) appear sufficient.

4: Evaluation using complex habits

Here, the method is evaluated using a variety of complex habits:

- Improved Geometric Optics Method (IGOM) used for optical properties
- 9 different habits described by Yang and Liou, 1998; Baum et al., 2011
- 3 different degrees of roughness
- 20 different size distributions applied

Figure above: For a cloud optical thickness of 5, asymmetry parameters of the complex habits are retrieved with a mean bias of 0.004±0.018.

Figure above:

A) The mean bias and standard deviation of retrieved asymmetry parameters are fairly independent of τ_{cloud}
B) τ_{cloud} is retrieved within 20%, and bias in scaled optical thickness is near zero.

5: Evaluation using habit mixtures

Here, 4 mixtures of ice habits by Baum et al. (2005; 2011) are used for evaluation, leading to similar results as seen for complex habits. However, for smooth habit mixtures that are dominated by aggregates of plates (Tropical convection), the asymmetry parameters are substantially overestimated.

7: Application to the Research Scanning Polarimeter (RSP)

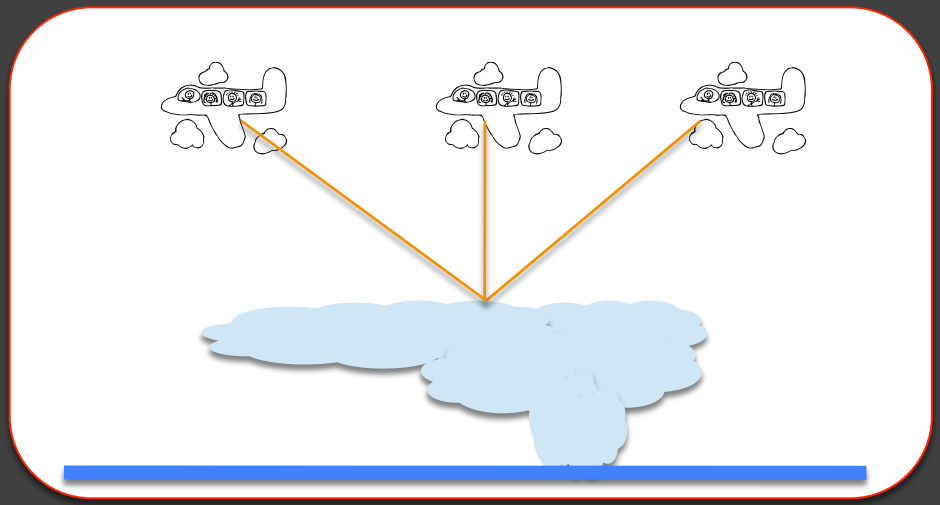
The asymmetry parameter retrieval approach is applied to RSP data collected during CRYSTAL-FACE.

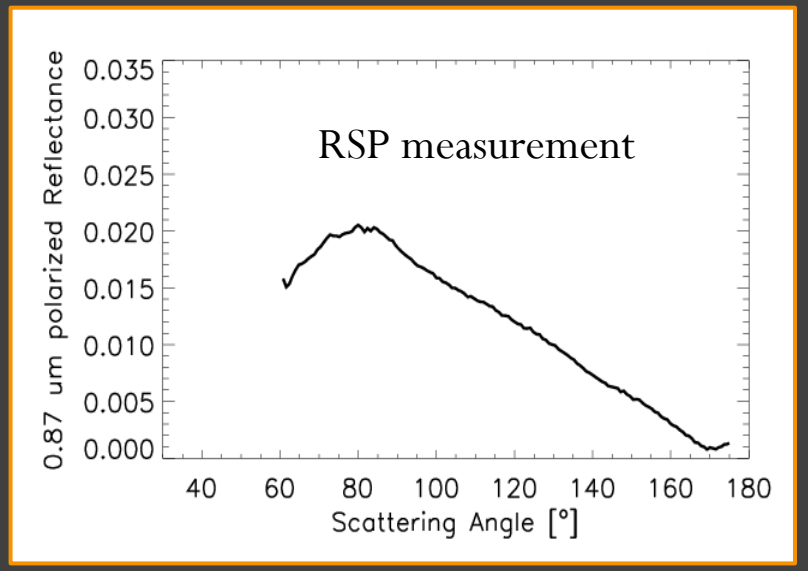
Preliminary results indicate asymmetry parameters of about 0.76-0.8 throughout the campaign.

Ice effective radii are also retrieved by RSP and are generally larger than values obtained by the MODIS airborne simulator (MAS), owing to the lower asymmetry parameter used in the RSP retrievals. (Thanks to the MAS team for providing MAS retrievals)

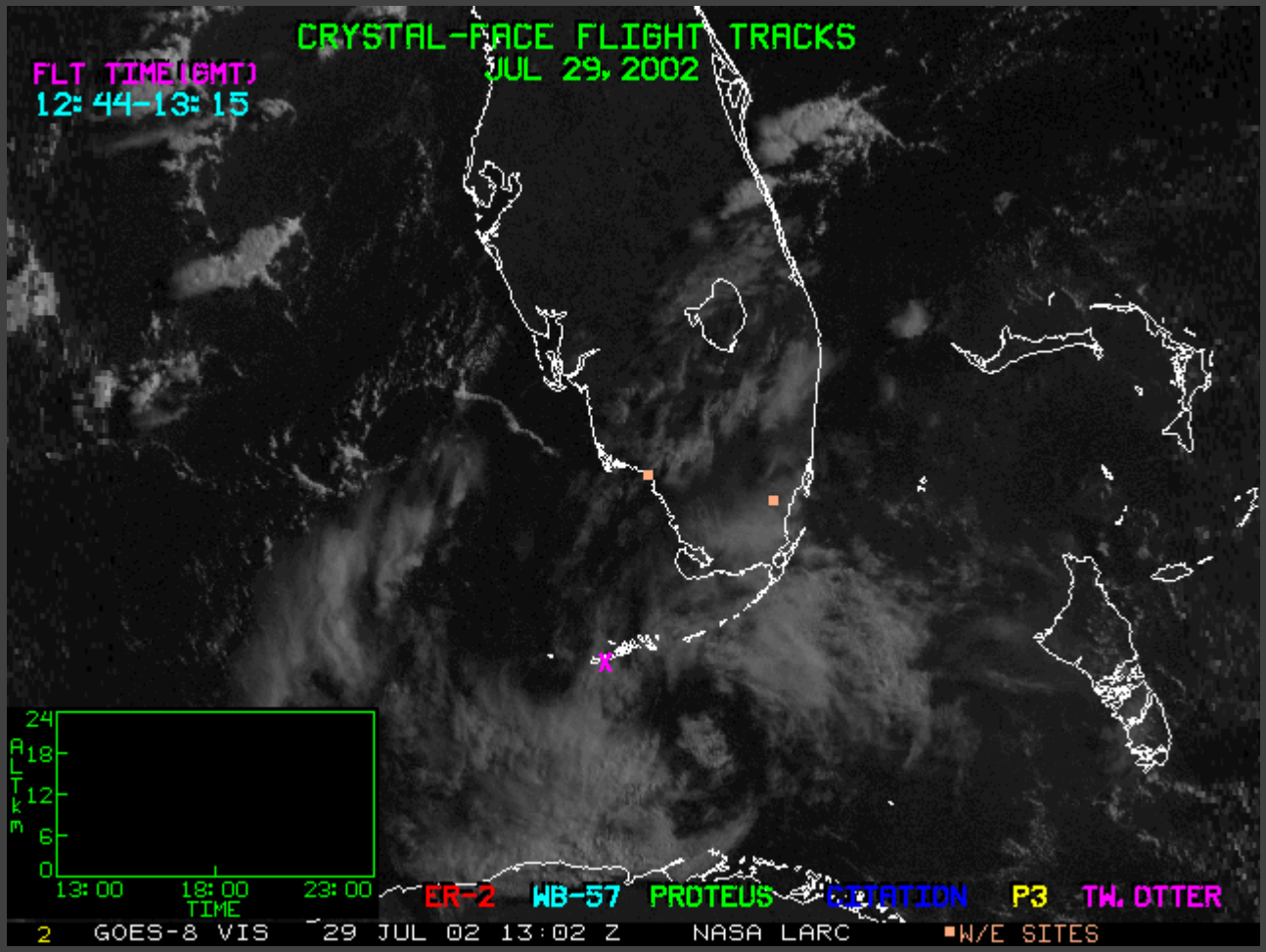
CRYSTAL-FACE: Research scanning polarimeter (RSP)

- Airplane version of Glory-APS (launch failed March 2011)
- Total and polarized reflectances
- 9 bands, visible to SWIR
- 152 viewing angles ±60°



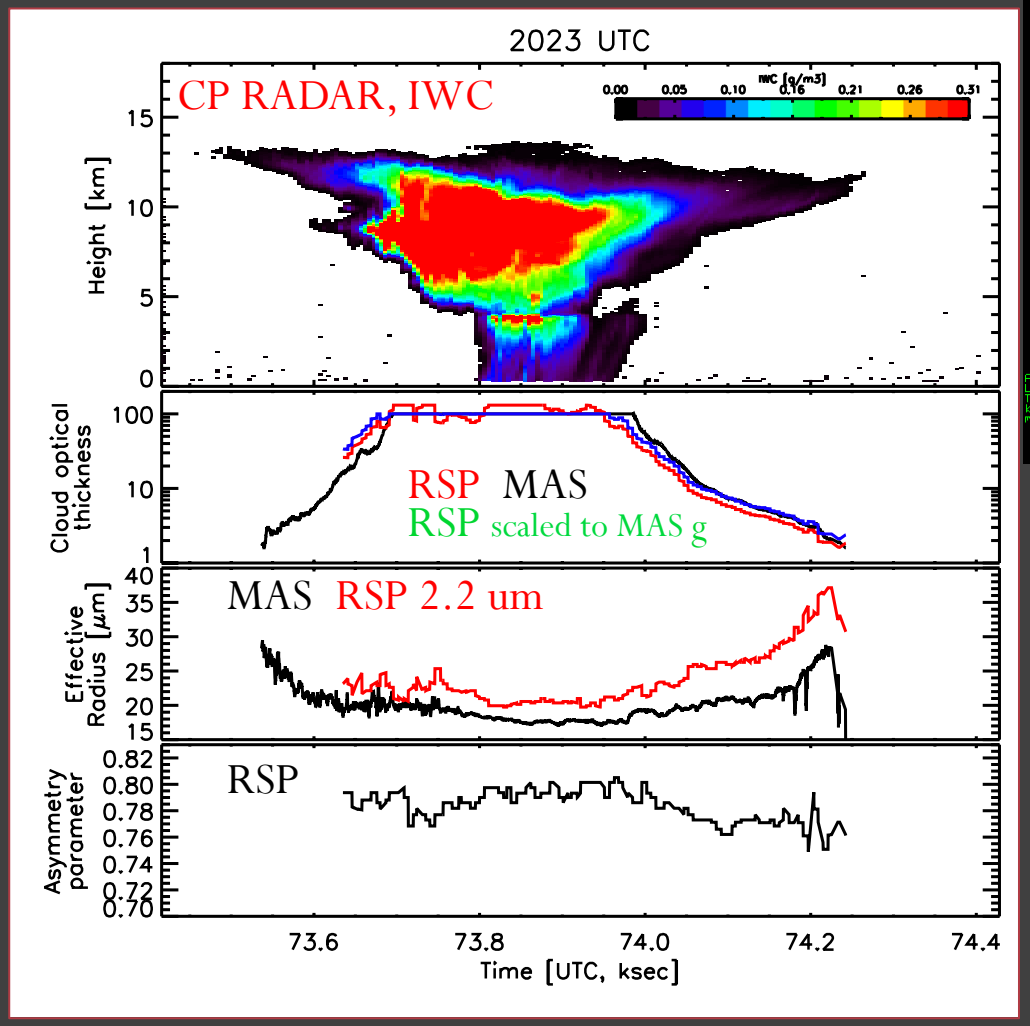


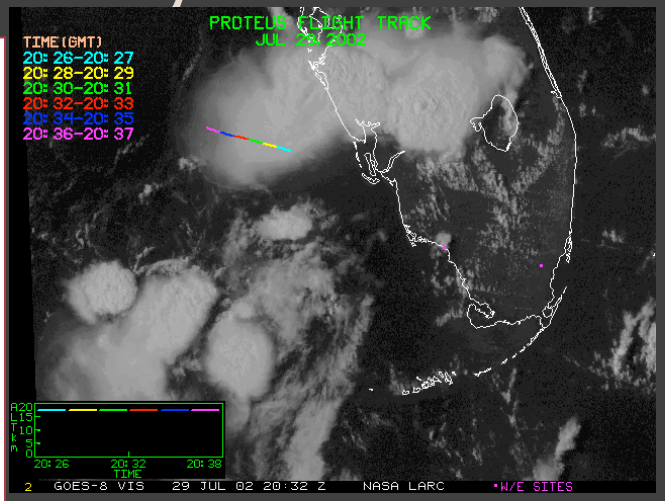
Aircraft flight tracks: 29 July 2002



http://www-angler.larc.nasa.gov/crystal/fltdays/all_072902/disp2002210.html

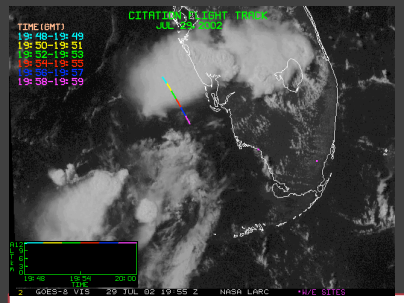
Application to RSP: 29th July 2002

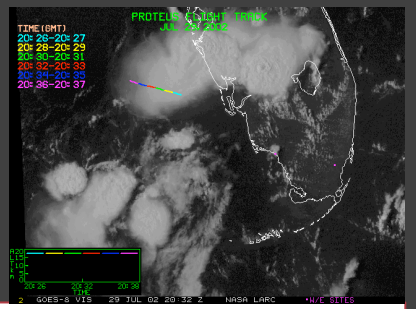


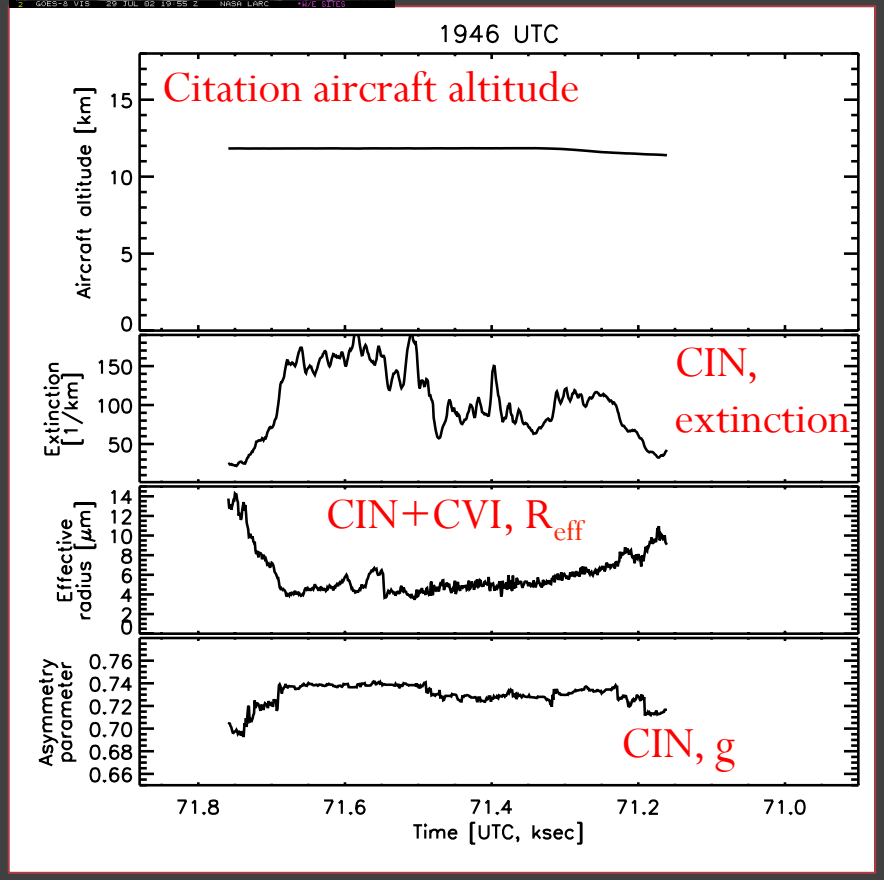


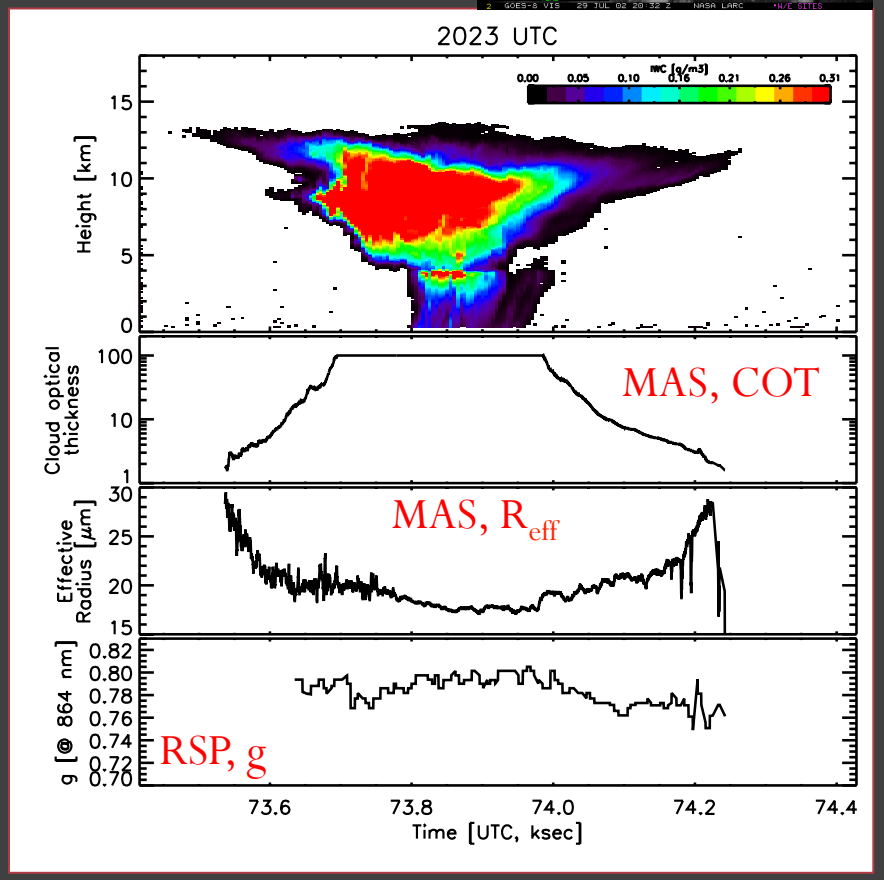
- MODIS collection 5 algorithm (g~0.83)
- Good comparison τ
- RSP R_{eff} ~2-8 μm higher due to lower g ~0.78
- RSP $\lambda = 1.6$ μm channel failed

Comparison with CIN in situ measurements (Tim Garrett)



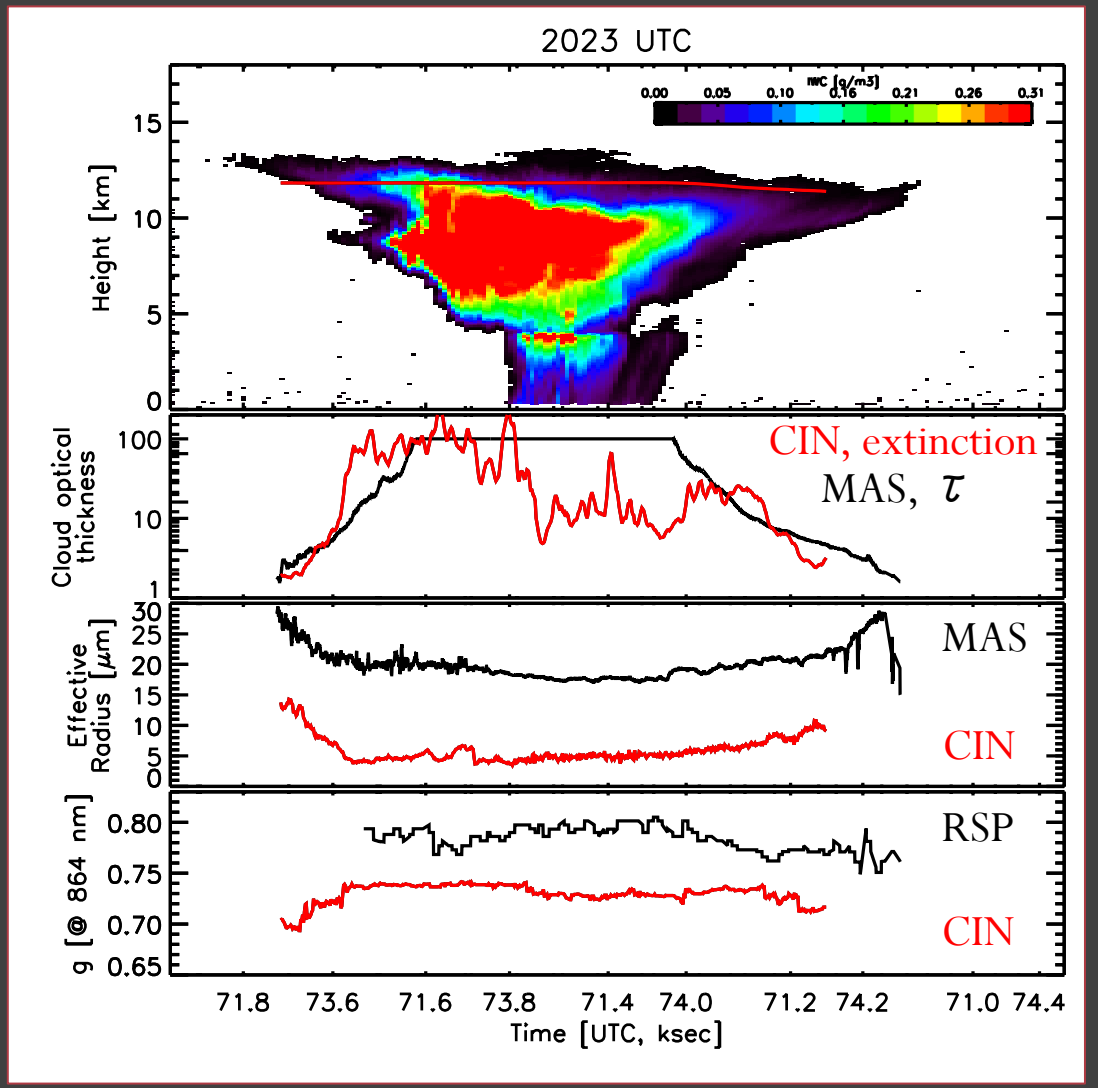




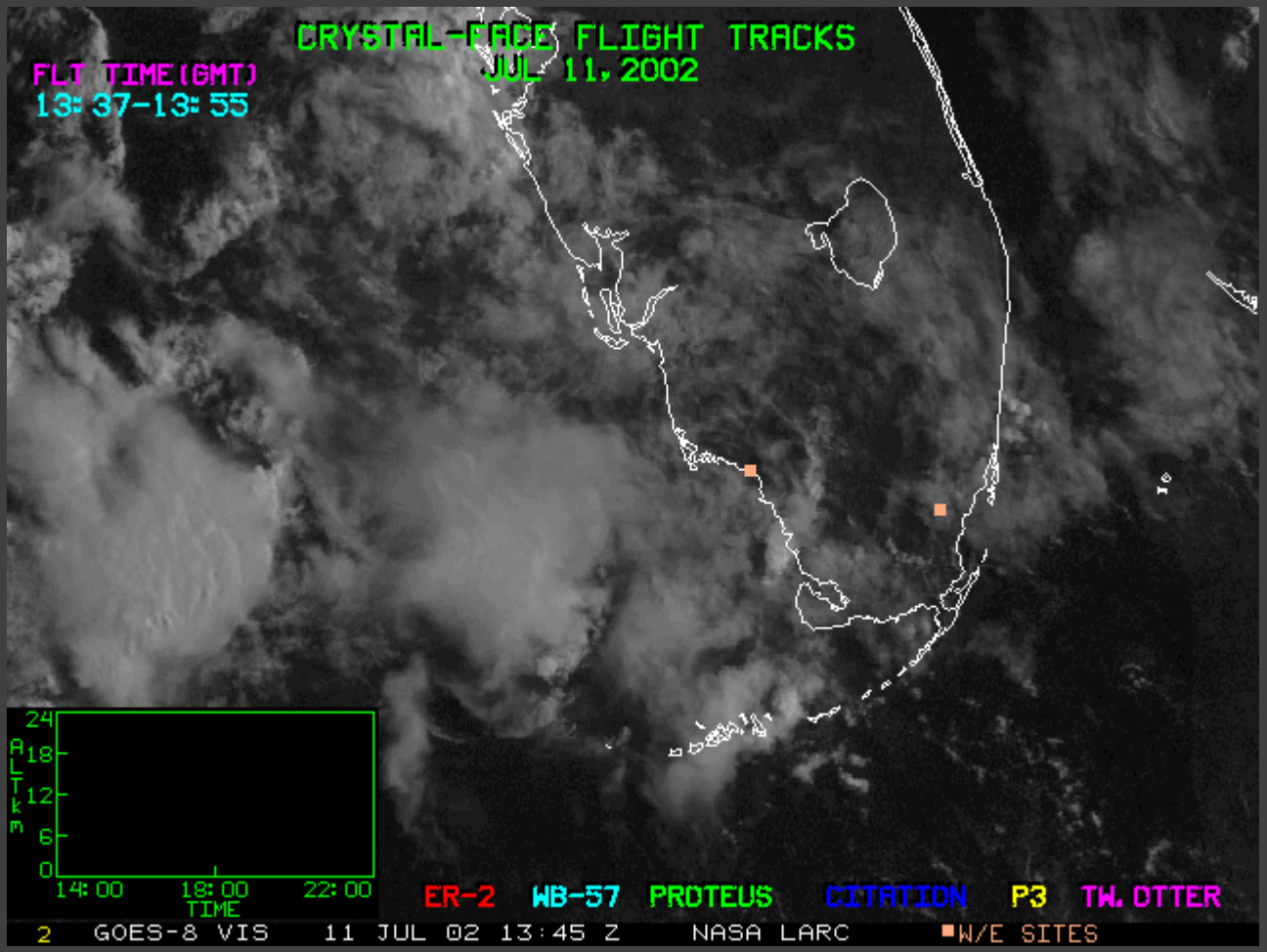


Comparison with in situ

- Δg ~0.04-0.07
- ΔR_{eff} ~ factor 3-4
  - cf. Heymsfield et al 2007
- CIN uncertainties:
  - Light leak correction
  - Calibration
  - Ice shattering on probe

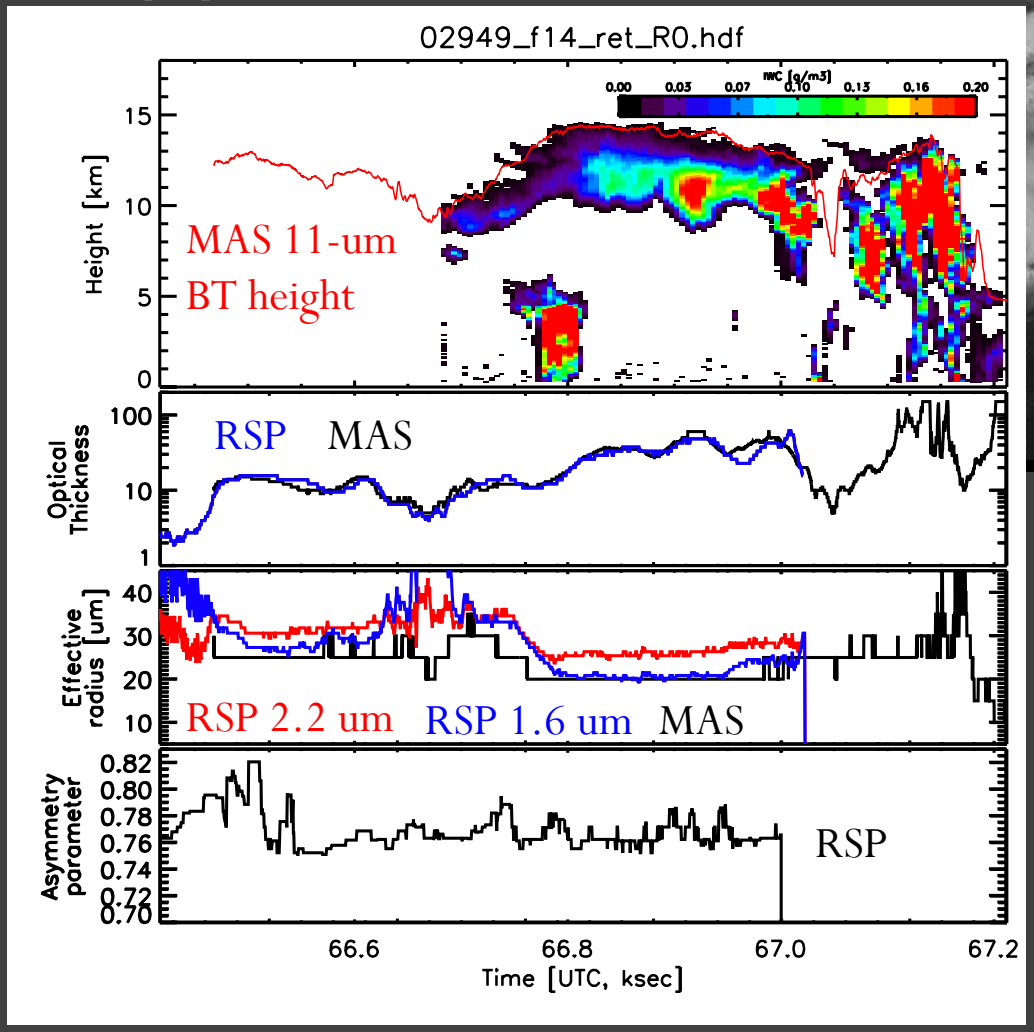


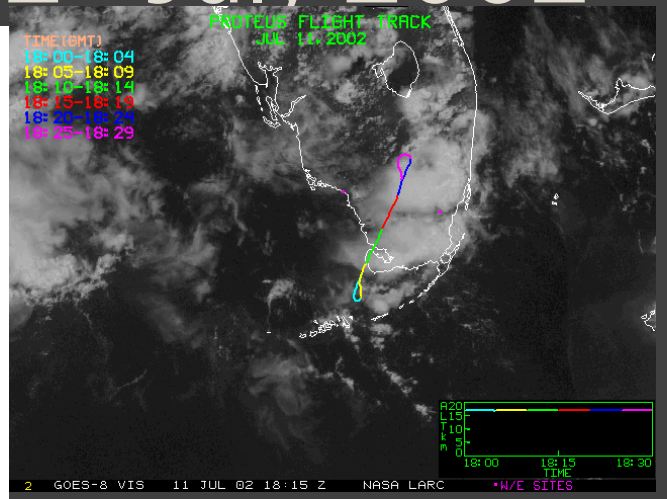
Aircraft flight tracks: 11 July 2002



http://www-angler.larc.nasa.gov/crystal/fltdays/all_071102_new/disp2002192.html

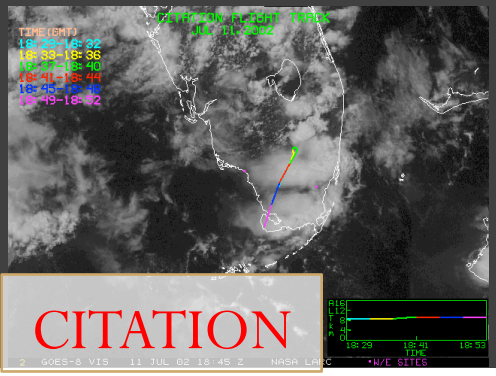
Application to RSP: 11th July 2002



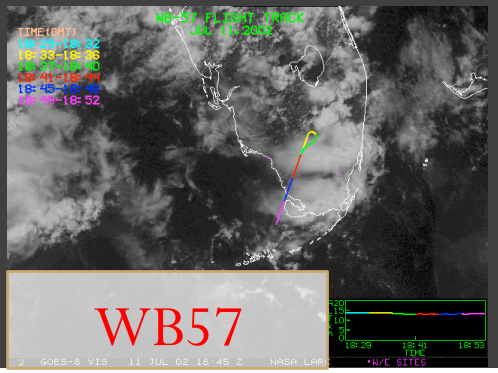


- Good comparison with MAS τ and Reff retrievals (collection 4)
- Asymmetry parameter g~0.76–0.78

CIN in situ measurements



CITATION



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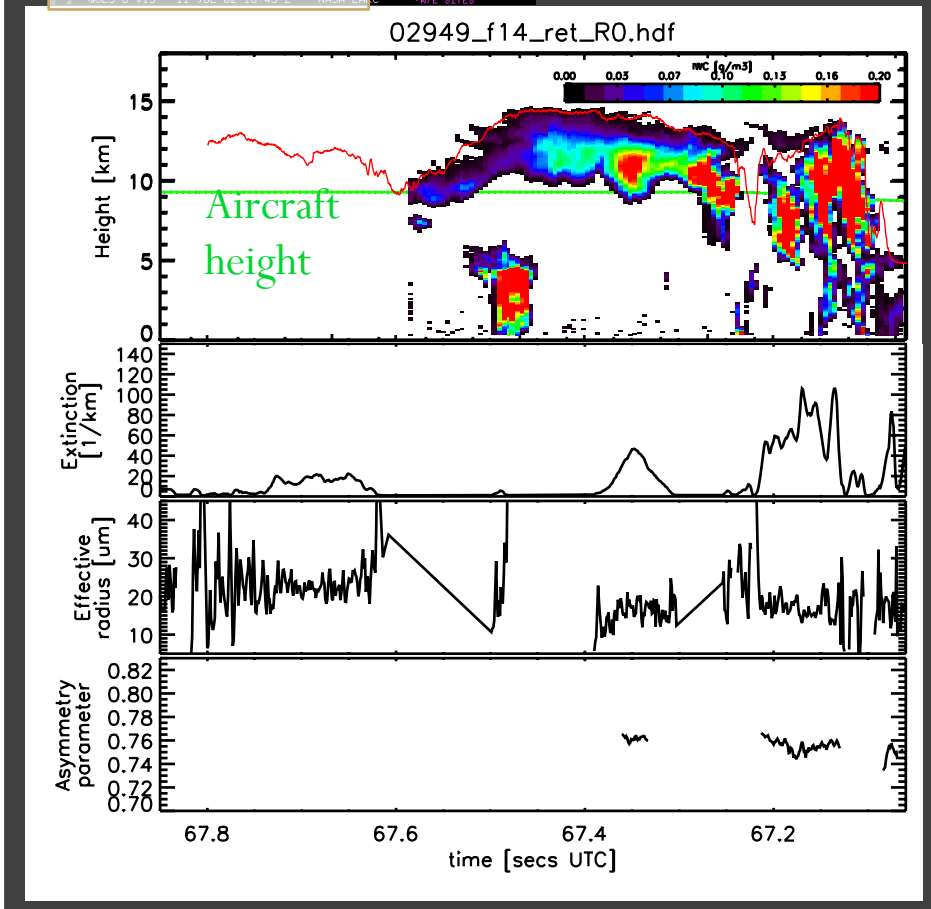
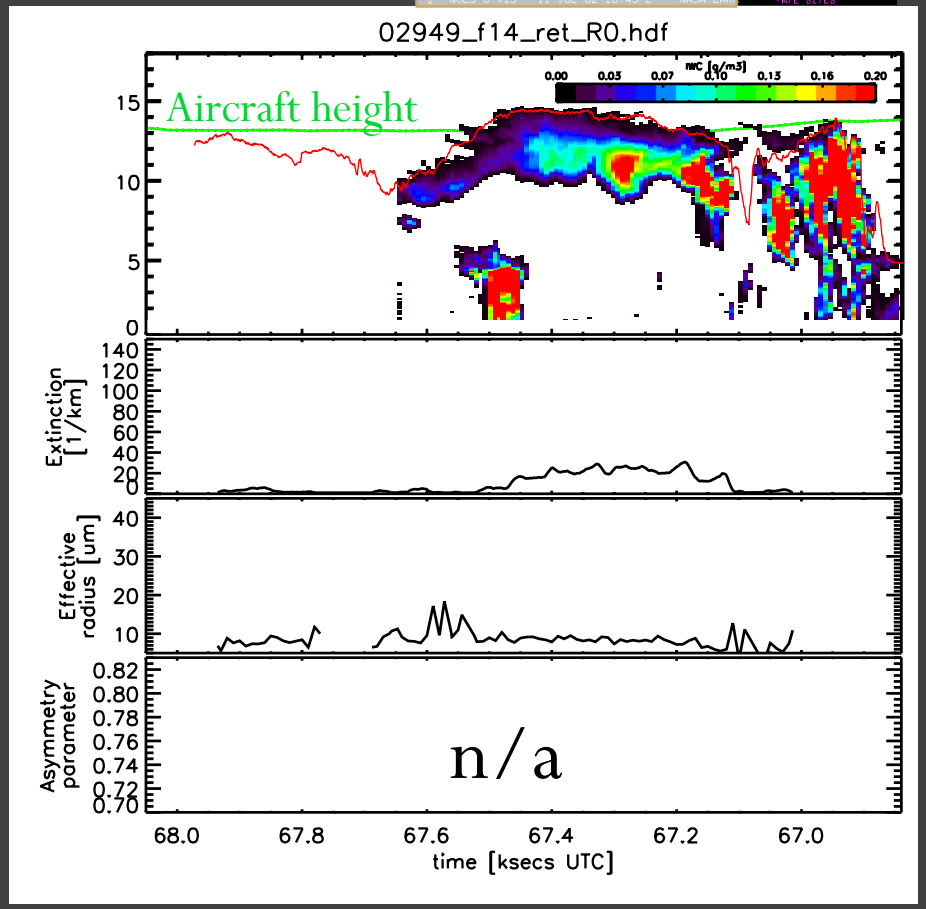
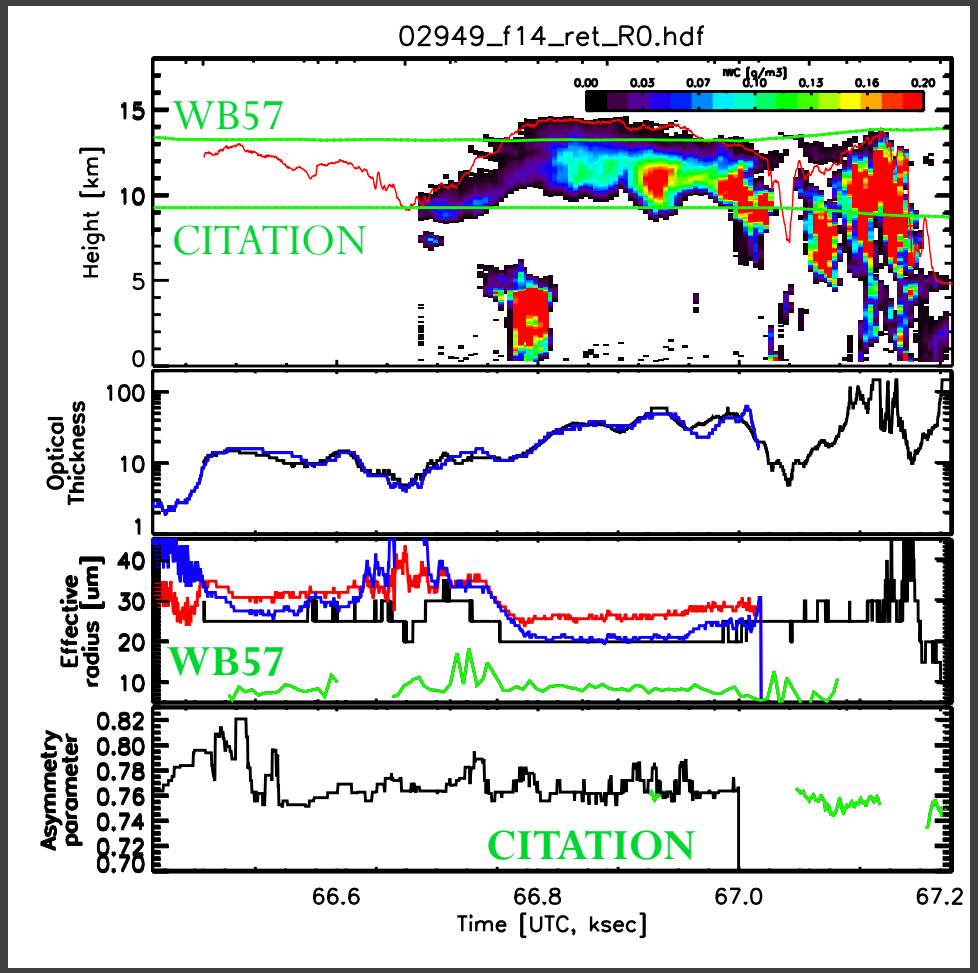


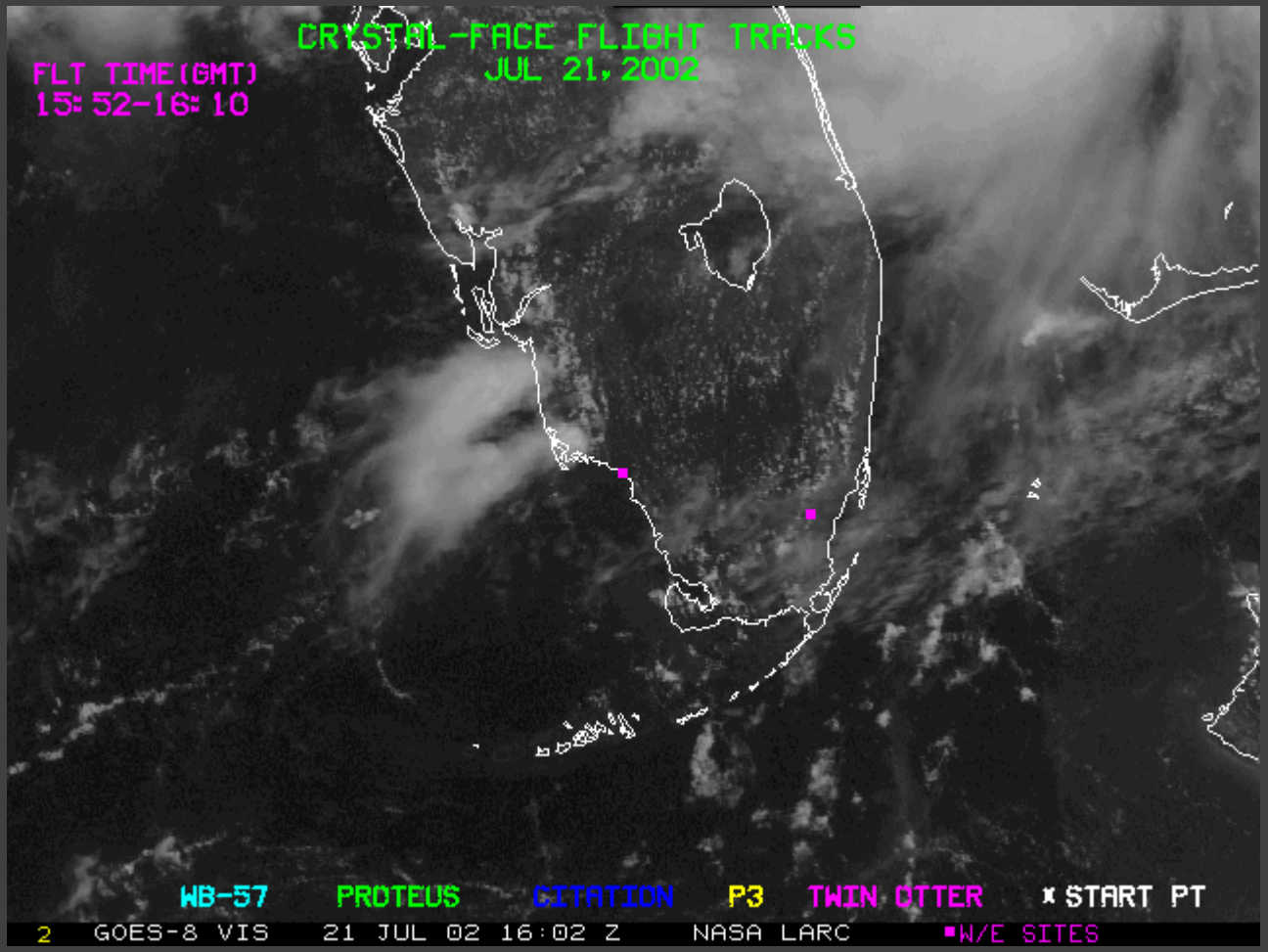


CIN vs MAS & RSP



- Asymmetry parameter
  - Good comparison CIN vs RSP (but CIN-Citation sampling cloud base)
- Effective radius
  - CIN factor 2-3 lower at top
    - cf. Heymsfield et al 2007

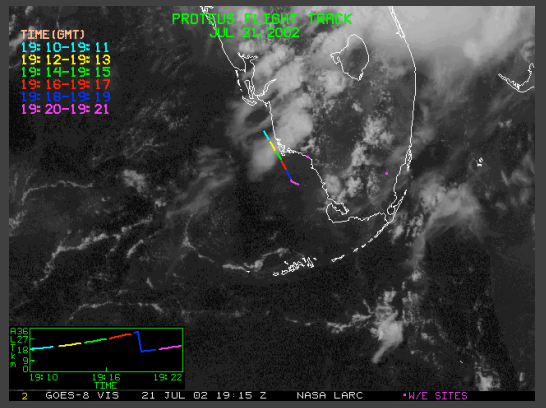
Aircraft flight tracks: 21 July 2002

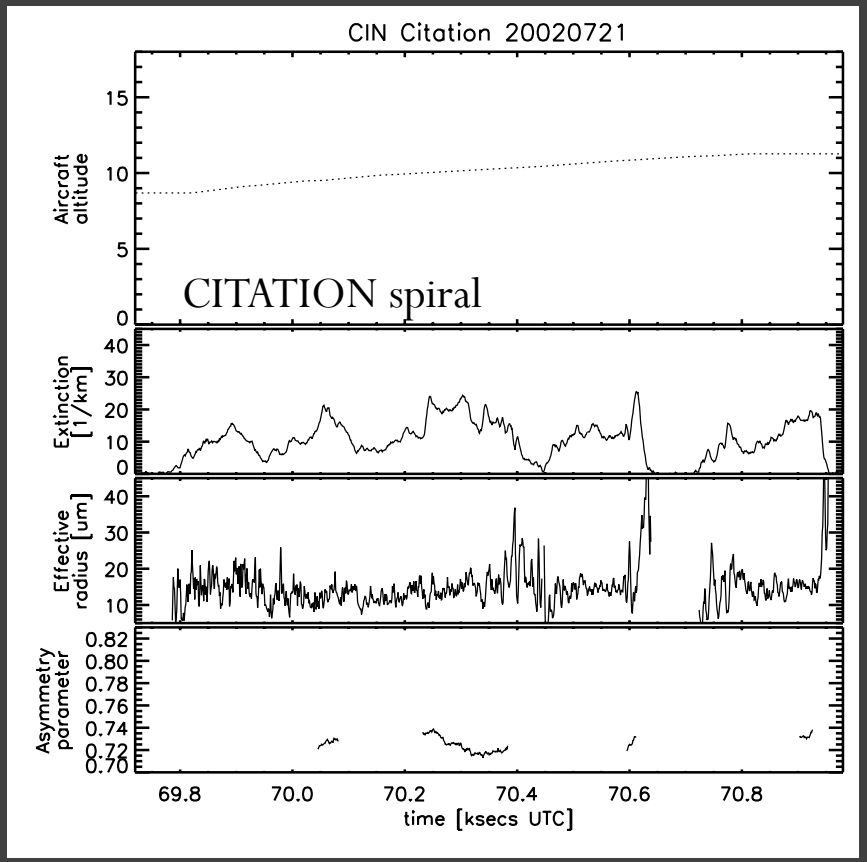


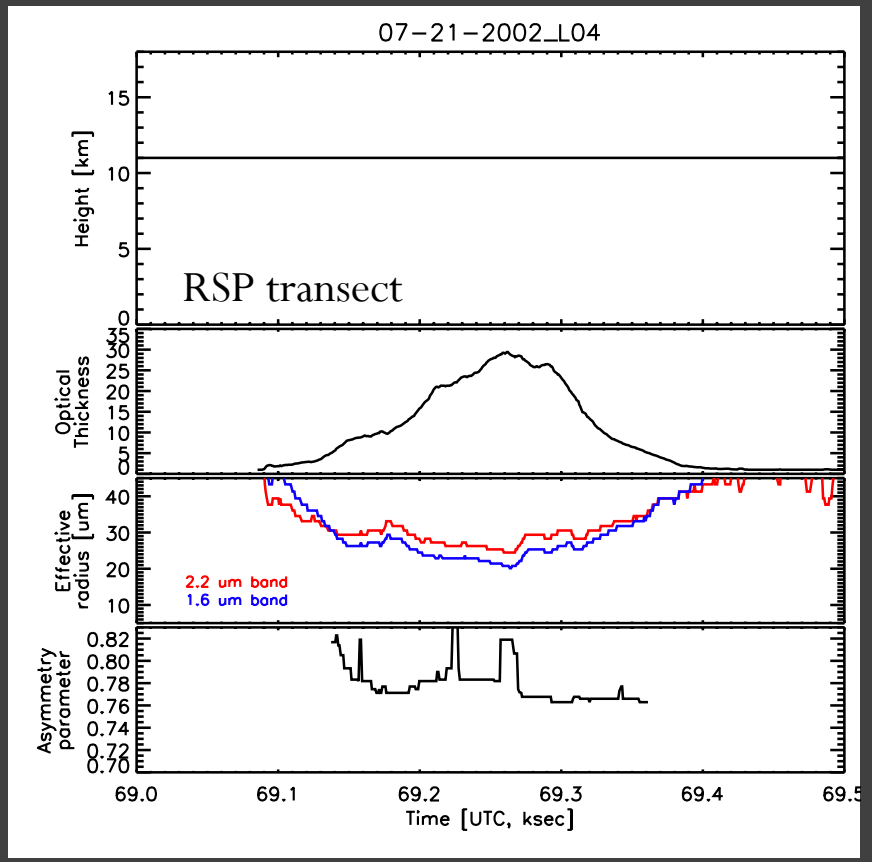
http://www-angler.larc.nasa.gov/crystal/fltdays/all_072102/disp2002202.html

CIN vs RSP 21 July 2002

- g = 0.76-0.78
- $\Delta g \sim 0.04$ (5%)
- $\Delta R_{eff} \sim$ factor 1.5-2







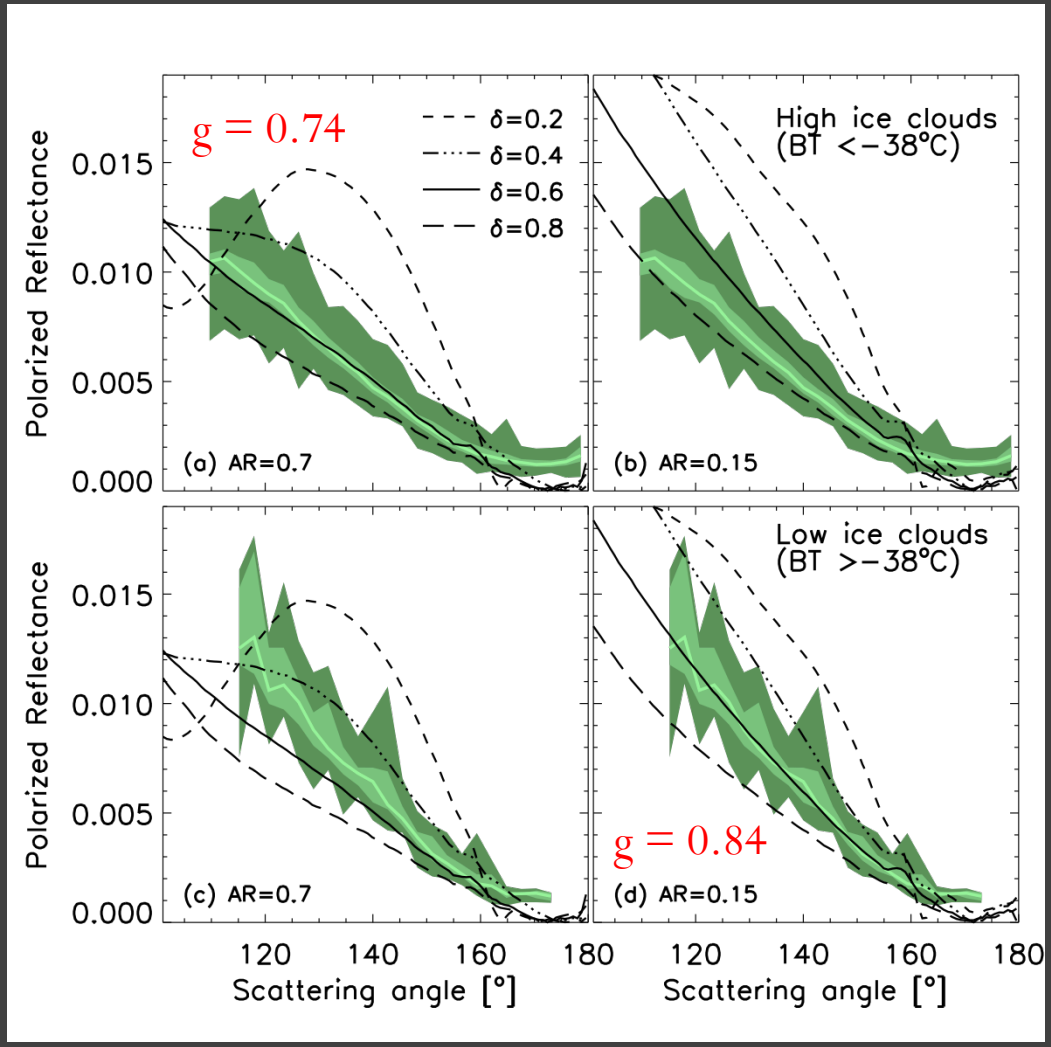
Preliminary conclusions from CRYSTAL-FACE

- g = 0.76-0.8
- No obvious correlation with R_{eff}, τ, Temp., etc.
- Short columns (AR=1-2) dominate
- Roughness ~0.3-0.5

- RSP g is biased high, up to 0.07 compared to CIN
- RSP R_{eff} and optical thickness compares well to MAS
- CIN R_{eff} is biased low compared to MAS and RSP
  - Factor 1.5-4, depending on case

Application to POLDER-PARASOL in A-train (van Diedenhoven et al., JAS, in press)

- Combined MODIS-POLDER data during TWP-ICE campaign
- $\tau_{cloud} > 5$ only
- AR~0.7 crystals in cold clouds, g=0.74 (homogeneous ice formation?)
- More extreme AR in warmer clouds, g=0.84 (heterogeneous ice formation?)



Future work

- Apply to more RSP data for validation
  - CRYSTAL-FACE
  - PODEX campaign (California, May-June 2012)
  - SEAC^{4}RS campaign (Southeast Asia, Aug.-Sept. 2012)
- Investigate error sources using cloud-resolving model
  - Inhomogeneous scenes
  - 3D radiative transfer effects
  - Vertical structure (multi-layered clouds)
- Global POLDER-MODIS data
  - Filter/aggregate data
  - Validation
- Advise MODIS team on ice crystal model to use

More on poster!

Remote sensing of ice crystal asymmetry parameter: evaluation with simulated measurements

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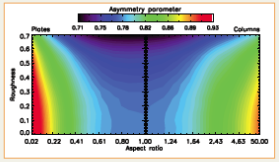

Figure above: Asymmetry parameters of plates and columns as a function of their aspect ratio and small-scale roughness.

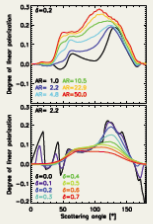

Figure left: Degree of linear polarization (DoLP) as a function of scattering angle. Colors indicate DoLP functions for varying aspect ratios (top panel) and roughness parameters δ (bottom panel).

To infer ice crystal asymmetry parameter from multi-directional polarized reflectance:

1) Single hexagonal ice columns and plates are assumed to serve as proxies for more complex shapes and aggregates
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- Geometric Optics code for optical properties (Macke et al., 1996)
- Columns and plates with 51 aspect ratios between 0.02 and 50
- 15 Roughness parameter values from 0 to 0.7
- A uniform cloud layer with varying optical thickness

3: Evaluation using bullet rosettes

Here, the retrieval approach is evaluated with simulated measurements calculated using optical properties bullet rosettes:

- Geometric Optics code used for optical properties
- 6 bullets per rosette
- 10 different bullet aspect ratios varying from 2 to 11
- 15 roughness parameter values from 0 to 0.7

Scattering angles between 100° and 165° with 84 sampling points are used in the retrieval.

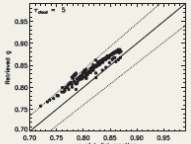


Figure left: For a cloud optical thickness of 5, asymmetry parameters of the bullet rosettes are retrieved with a mean bias of 0.02±0.01.

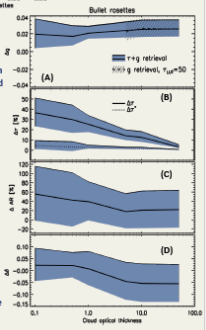


Figure right:

A) Mean bias (solid line) and standard deviation (blue) of retrieved asymmetry parameter depend little on τ_{cloud}. For τ_{cloud}>5, polarized reflectances saturate and look-up-tables with any large τ_{cloud} can be applied without the need to retrieve τ_{cloud} (dashed line and line-shaded area)
B) Retrieved τ_{cloud} is biased owing to the bias in asymmetry parameter. Scaled optical thickness is retrieved within 10%.
C) The aspect ratios of the bullets in the rosette are retrieved within 20±40% for τ_{cloud}>5, but bias increase for optically thinner clouds.
D) Roughness parameters are retrieved rather well.

4: Evaluation using complex habits

Here, the method is evaluated using a variety of complex habits:

- Improved Geometric Optics Method (IGOM) used for optical properties
- 9 different habits described by Yang and Liou, 1998; Baum et al., 2011
- 3 different degrees of roughness
- 20 different size distributions applied

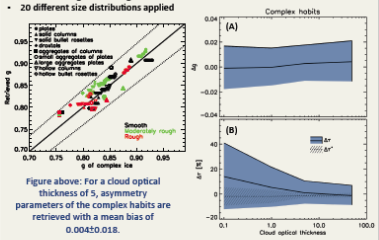


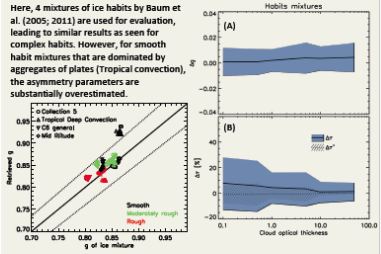
Figure above: For a cloud optical thickness of 5, asymmetry parameters of the complex habits are retrieved with a mean bias of 0.004±0.018.

Figure above:

A) The mean bias and standard deviation of retrieved asymmetry parameters are fairly independent of τ_{cloud}
B) τ_{cloud} is retrieved within 20%, and bias in scaled optical thickness is near zero.

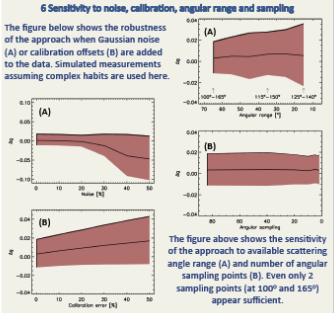
5: Evaluation using habit mixtures

Here, 4 mixtures of ice habits by Baum et al. (2005; 2011) are used for evaluation, leading to similar results as seen for complex habits. However, for smooth habit mixtures that are dominated by aggregates of plates (Tropical convection), the asymmetry parameters are substantially overestimated.



6 Sensitivity to noise, calibration, angular range and sampling

The figure below shows the robustness of the approach when Gaussian noise (A) or calibration offsets (B) are added to the data. Simulated measurements assuming complex habits are used here.



The figure above shows the sensitivity of the approach to available scattering angle range (A) and number of angular sampling points (B). Even only 2 sampling points (at 100° and 165°) appear sufficient.

7: Application to the Research Scanning Polarimeter (RSP)

The asymmetry parameter retrieval approach is applied to RSP data collected during CRYSTAL-FACE.

Preliminary results indicate asymmetry parameters of about 0.76-0.8 throughout the campaign.

Ice effective radii are also retrieved by RSP and are generally larger than values obtained by the MODIS airborne simulator (MAS), owing to the lower asymmetry parameter used in the RSP retrievals. (Thanks to the MAS team for providing MAS retrievals)